Population assessment of the endangered Green and Golden Bell Frog *Litoria aurea* at Port Kembla, New South Wales

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ABSTRACT

The Green and Golden Bell Frog *Litoria aurea* has declined dramatically in distribution and abundance in NSW during the last 20 years. We describe the dynamics of the population found at Port Kembla near Wollongong, New South Wales during 1994–6. This population was formerly widespread in the region but has contracted to just four sites, all found within a distance of 5 km. We conducted detailed surveys at three of these sites and a preliminary survey at the fourth site. These surveys revealed that only two of the sites contained breeding habitat that may have any short-term security. One of these breeding sites (Coomaditchy Lagoon) contained high densities of the Mosquito Fish *Gambusia affinis*, however, tadpole survival and adult recruitment at this site appeared high. In January 1996, more than 400 metamorphlings were observed. Ten months later there was a substantial increase in the number of adult bell frogs present at the site. The other site where significant breeding occurred was within the BHP steel works. There was limited breeding at a third site which has been subjected to development for new housing. The adult frog population appeared to move amongst some sites offering breeding habitat; many residents in the area reported the presence of frogs sheltering on their properties. We provide several management options for this frog population including closer study of the fish-tadpole interaction at the lagoon site. Resolution of this anomaly offers the opportunity to not only secure many existing populations but also to manage unoccupied breeding sites that are currently unavailable to frogs due to the presence of the Mosquito Fish.

INTRODUCTION

A fundamental component of conserving endangered species in the wild is the establishment of a population monitoring programme (e.g., Minta *et al.* 1990). This can be used to guide changes in management actions and is particularly critical for species reduced to very low numbers. Such monitoring has recently been effective in determining the status of declining frog populations in north Queensland (Richards *et al.* 1993).

The Green and Golden Bell Frog *Litoria aurea* ranged historically from Byron Bay in northern New South Wales, along the coast and adjacent highlands, south to east Gippsland in Victoria (Cogger 1992). It has undergone a well documented range reduction and population decline in the last 20 years (Osborne *et al.* 1996; White and Pyke 1996). The species has not declined in Victoria (Gillespie 1996) but as the decline in New South Wales has not been arrested, it is possible that this will eventually extend into Victoria. Given the poor level of knowledge about the ecological requirements of most Australian frogs, this species could serve as an important model for the management and conservation of other species.

There are only four sites in New South Wales where populations of the Green and Golden Bell Frog number 20 or more individuals (White and Pyke 1996), including one location near Wollongong. There is a clear need to begin annual monitoring of all occupied sites in order to determine whether remaining populations are stable or still declining. Indeed, such monitoring will be needed at sites where active management is taking place. No standard survey method has been developed for this species, but counts of calling males under appropriate weather conditions may provide a useful index of population size (Goldingay 1996).

The aims of this study were: i) to develop a method for monitoring the population of bell frogs at Port Kembla, Wollongong, and ii) to establish a baseline population count.

METHODS

Study animal

The snout-vent length of females in this population ranged from 66 to 86 mm (mean 76.0 ± 1.7; n = 14) while that of males ranged from 60 to 75 mm (mean 62.3 ± 3.9; n = 17) (van de Mortel 1996). We considered individuals greater than 50 mm in snout-vent length to be adults. Spawn sizes ranged from 2 463 to 11 682 (mean 5 706 ± 947; n = 8) (van de Mortel 1996).

Study area

This study was conducted at sites near Port Kembla, in the Illawarra region of southern New South Wales. Detailed surveys were conducted at four sites: Coomaditchy Lagoon, Gloucester Boulevard, BHP steelworks and Korungulla Wetland. These sites appear to contain the only extant populations of the Green and Golden Bell Frog in this region (unpubl. data). Coomaditchy Lagoon is a natural lagoon of approximately 2 ha in area and is a reserve managed by the Wollongong City Council (Fig. 1). The lagoon is surrounded by grass lawns adjacent to roads on three sides and vegetated sand dunes on the south side. The lagoon has extensive fringing areas of cumbungi *Typha domingensis* and a large area of tall spikerush *Eleocharis sphacelata* at one end. The lagoon is a feeding and resting place for many species of waterbird and contains a population of common Long-necked Tortoises *Chelodina longicollis*. It also contains a high density of the introduced Mosquito Fish *Gambusia affinis*. Following heavy rainfall, a large ephemeral pond (30 m × 70 m) develops to the east of the lagoon. The pond and lagoon are joined by a drainage channel approximately 80 m in length. No fish were seen in the ephemeral pond, and there appeared little opportunity for tadpoles in the pond to make their way into the lagoon.

The site on Gloucester Boulevard is privately owned and located about 1 km north-east of Coomaditchy Lagoon. The site is bounded by houses to the south and factories to the north. The area is elevated to the west, sloping down to the boulevard and beach to the east. The drainage pattern allows ephemeral ponds to develop on the site and the adjacent factory property after heavy summer rain. The larger of the ephemeral ponds is drained by a channel which empties on to the beach. The drainage channel has a small area of natural vegetation and several small areas of *Typha*. A sedimentation pond was established at the front of the property in 1994 following earthworks on the site. This pond was subsequently filled in by order of the Environmental Protection Authority leaving a small ephemeral puddle with *Typha* and some grasses surrounding it. The site is fish-free.

The BHP site consists of a constructed permanent pond (approximately 0.2 ha) which is surrounded by grasses and weeds such as *Lantana camara*. The site is situated near a drainage channel containing *Typha*, and is located about 2 km north of Coomaditchy Lagoon. Korungulla Wetland is located in Primbee, about 2 km south of Coomaditchy Lagoon. The wetland was given to the Wollongong City Council as a reserve following completion of sand mining at the site. It contains three separate ponds or swamps (each at least 0.5 ha) which are heavily vegetated with *Typha*.

Other sites at which bell frogs had been seen previously such as the Primbee Golf Course (L. Smith, pers. comm.), or which contained suitable habitat, were surveyed for bell frogs during the summer period. Bell frogs were not found at any of these other sites.

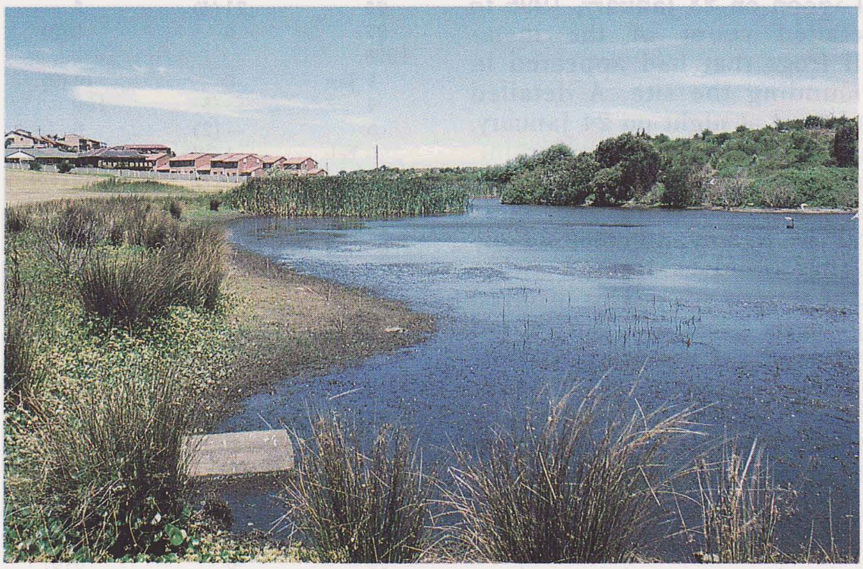

Figure 1. Habitat of the Green and Golden Bell Frog at Coomaditchy Lagoon. Adult male bell frogs aggregate around the edges of the lagoon (shown in foreground) at night and reside in the beds of cumbungi during the day. Metamorphling frogs have been observed in thick grass around the entire perimeter of the lagoon.

Frog surveys

Gloucester Boulevard and Coomaditchy Lagoon were the primary survey sites in this study. Each site was visited initially in early October 1994 in order to collect spawns from amplecting pairs for use in field experiments on egg hatchability (van de Mortel 1996; van de Mortel and Buttemer 1996). Frogs were detected readily at the former site which became the primary survey site in 1994 and early 1995. Both of these sites were visited regularly in late 1995 and early 1996.

As early surveys showed that amplecting pairs tended to form around 2300–2400 hours, most of the following surveys were conducted during this period. During each visit to a site, a hand-held spotlight was used to survey all suitable habitat. At Gloucester Boulevard, this included walking the length of the drainage channel and examining any areas where ephemeral ponds may have developed. At Coomaditchy Lagoon it included walking the full perimeter of the lagoon and the adjacent ephemeral pond site. During these surveys, all bell frogs seen and heard calling were counted. This included attempting to determine the exact number of calling male frogs in all areas that could not be viewed directly due to the inaccessibility of the aquatic vegetation or the depth of the water. Korungulla Wetland was visited on eight different occasions in late 1994 to late 1995. Two visits were made to the BHP site in January and February 1996.

Day-time surveys were conducted around Coomaditchy Lagoon on 23 January, 1996 to provide a detailed count of the metamorphling bell frogs that had appeared in the grass surrounding the site. A detailed survey was conducted at night on 24 January, 1996 as a comparison with the diurnal count. These surveys entailed two people walking within 2 m of each other, in the same direction around the lagoon and counting any juvenile frogs that could be located within about 20 m of the water's edge. This involved walking through long grass and during the day, frequently parting the grass to reveal any frogs that may have been sheltering lower down. At night, it was found that juvenile frogs tended to sit in exposed positions on top of the grass or on other substrates.

For each survey date, the temperature and overnight rainfall were recorded either at the site, or from the Bureau of Meteorology reports for Wollongong. Water temperatures were recorded during surveys at Coomaditchy Lagoon in late 1995 and early 1996.

Influence of weather parameters

The influence that temperature and rainfall have on bell frogs was assessed by recording these parameters when counts were made of calling males. We used the partial correlation to relate temperature and rainfall variables to the number of frogs recorded because it adjusts the correlation coefficient of a pair of variables while holding each other variable constant (Zar 1984). The data for the two sites (transformed by ln (x + 1) to improve normality) were analysed in different ways to reflect the different temperature variables recorded.

RESULTS

Gloucester Boulevard

Bell frogs were frequently encountered at this site in late 1994 (Table 1), most of which were calling males. A maximum number of 26 frogs was detected in December

Table 1. Number of *Litoria aurea* adults and concurrent weather variables recorded at Gloucester Boulevard. Pairs = pairs of frogs in amplexus, all dates without a value are zero, — = no data. Rainfall is the rain received in the 24 h up to 9 00 h on the date; value in brackets is the rain in the previous 24 h.

Date	Number of adults (pairs)	Rainfall (mm)	Max. temperature (°C)
1994			
21 Oct	0	24 (13)	17
29 Nov	9	19 (4)	25
30	9	6	27
1 Dec	3	1	19
9	0	19 (0)	17
23	26 (2)	5 (0)	26
24	— (1)	18	21
25	21 (4)	8	23
27	0	0 (9)	30
1995			
3 Jan	0	14 (9)	20
4	— (5)	109	25
5	— (2)	6	26
6 Feb	1	2	21
12	— (1)	30 (18)	25
15	1	0	25
18	0	0 (10)	—
25	0	0 (0)	27
2 Mar	0	7 (12)	21
10 Apr	0	0 (—)	19
2 Sept	0	0 (0)	20
27	0	0 (7)	17
28	1	0	18
19 Oct	2	— (0)	25
22	0	55 (—)	19
26 Nov	0	0 (0)	21
1996			
17 Jan	0	0 (0)	25
23	9	17 (9)	25
24	6	29	22
29	0	0 (0)	26
1 Feb	0	0 (0)	27
12	0	2 (8)	24
22	0	0 (10)	22
26	3	4 (2)	24

1994. Calling males were found in the sedimentation pond, in an ephemeral pond at the western end of the site and in the drainage channel that linked the two. Amplecting pairs were found during this period, including two male-male pairs. Surveys conducted approximately 10 days later revealed further amplecting pairs of frogs. Visits to the site in late 1995 and early 1996 showed that frogs were still present but in lower numbers (Table 1).

Coomaditchy Lagoon

Consistent numbers of bell frogs were found at this site during late 1995 and early 1996 (Table 2). Twenty-six frogs were recorded at Coomaditchy in December 1995, which was similar to the maximum number counted at Gloucester Boulevard in 1994. In November, 1996, a total of 63 adults were counted around the lagoon. Only five amplecting pairs were located overall despite the greater number of calling males at this site.

Korungulla Wetland and BHP

Two male bell frogs were located at the Korungulla Wetland site on three different occasions. One male called in response to a taped chorus of *Litoria aurea*, but no breeding activity or bell frog tadpoles were observed at this site during the summers of 1994/5 and 1995/6.

In response to a request for an identification of tadpoles, a visit was made to the BHP site on 15 January, 1996. Tadpoles were numerous and were identified as bell frog tadpoles. A subsequent nocturnal visit made on 19 February, 1996 found five adults, three juveniles and 16 metamorphs.

Table 2. Numbers of *Litoria aurea*, rainfall (mm) and temperature (°C) recorded at Coomaditchy Lagoon. Pairs and rainfall as for Table 1. S = 20m² sub-site that was monitored for juvenile bell frogs. R = 1 road-killed adult frog observed. D = day count.

Date	Number of adults (pairs)	Number of juveniles	Rainfall	Max. temperature	Air temperature	Water temperature
1995						
18 Oct	12	0	0 (0)	18	—	—
19	1	0	—	—	—	—
20	9	0	0	19	—	—
22	0	0	55 (0)	18	16	—
1 Nov	6	0	0 (1)	19	17	—
2	9	0	1	28	20	—
15	0	0	0 (0)	26	—	—
26	10	0	0 (—)	24	22	17
27	15 (1)	0	4	35	—	—
29	24	0	2 (0)	24	24	23
2 Dec	26 (1)	0	1 (13)	22	19	22
10	16	0	0 (—)	28	17	22
12	0	0	0 (0)	20	15	18
18	18	30	3 (0)	29	19	23
26	13 (1)	103	0 (—)	23	22	22
27	15	60	4	24	19	20
1996						
7 Jan	18 (1)	59	0 (—)	21	21	24
9	13	—	1 (0)	25	20	22
11	13	—	2 (0)	24	21	24
17	0	—	0 (0)	25	22	23
18	0	—	1	24	24	25
19	2	9^{S}	0	28	22	25
23	0	196^{D}	17 (9)	25	20	24
24	0	422	29	22	—	—
29	0	—	0 (0)	26	20	21
1 Feb	0	—	0	27	24	23
3	0	20^{S}	0 (0)	25	20	23
5	0	—	2 (2)	25	—	—
12	0	—	8 (8)	19	—	—
15	0	0	1 (2)	21	—	—
22	0	9^{S}	0 (11)	22	—	—
26	0	0	4 (2)	24	—	—
28	1^{R}	10^{S}	0 (0)	26	—	—
1 Mar	0	—	12 (11)	23	—	—
9	0	—	9 (2)	21	—	—
16 Oct	6	1	0 (0)	28	—	—
25 Nov	59	0	0 (0)	27	—	—
26	63 (1)	1	0	30	—	—

Breeding activity at the four survey sites

Metamorphling bell frogs began to appear at Coomaditchy Lagoon in mid December 1995 (Table 2). These numbers increased over time but a detailed count of the entire lagoon was not conducted until late January. Approximately 200 metamorphlings were counted during the day, but a subsequent systematic nocturnal count around the perimeter of the lagoon revealed that more than 400 metamorphling bell frogs were present (Table 2). At this time over 100 very large (8 cm) tadpoles were observed in the water, and many metamorphlings had rudimentary tails when they were first seen. One dispersing individual observed on the roadside about 100 m from the lagoon retained a tail longer than its snout-vent length. A detailed count was not attempted again but monitoring of a small sub-site suggested that the number of juvenile frogs remained high until late February (Table 2), despite large numbers of metamorphlings dispersing from the site across surrounding roads.

Hundreds of bell frog tadpoles were seen during the visits to the BHP site in January and February 1996, showing that this is an important breeding site for bell frogs in the area. Only six tadpoles were seen at the Gloucester Boulevard site in the breeding season of 1995/6. These were found in several small puddles in the drainage channel and in the puddle near the road which had previously been the sedimentation pond.

Influence of weather parameters

At Gloucester Boulevard, we examined the relationship between the number of adult frogs and the maximum temperature and rainfall recorded at Wollongong on the day of the census ($n = 27$). This showed significant correlations between the number of frogs and rainfall ($r = 0.493$, $P < 0.02$) and the number of frogs and temperature ($r = 0.436$, $P < 0.05$). When rainfall for the previous 24 h period (i.e., rain for 48 h) was included in the correlation, there was a significant relationship between the number of frogs and rainfall ($r = 0.414$, $P < 0.05$) but not between the number of frogs and temperature ($r = 0.266$, $P > 0.1$). When the zero frog values were removed from the first analysis which reduced the sample size ($n = 11$), these correlations were not significant (rain: $r = 0.564$, $P > 0.05$; temperature: $r = 0.381$, $P > 0.2$). A similar result was obtained when the rainfall for the previous 24 h was included.

At Coomaditchy Lagoon, the number of adult frogs was related to rainfall and to the air and water temperatures recorded at the lagoon at the time of the census (Table 2). Only those occasions when all variables were recorded were analysed ($n = 18$). There was no significant relationship between frog numbers and air and water temperatures (air: $r = -0.036$, $P > 0.5$; water: $r = -0.051$, $P > 0.5$) or with rainfall ($r = -0.122$; $P > 0.5$). Including rainfall for the previous 24 h did not change this result.

Coomaditchy Lagoon was visited at night after the breeding season in 1996 to determine whether frogs were still present at the site during the cooler months. Four subadults were observed on 18 May when the ambient temperature was 18°C. Visits on 11 and 30 June revealed three and two subadult frogs respectively, when the temperatures were 14°C and 16°C.

DISCUSSION

This study reports on the dynamics of the Green and Golden Bell Frog population around Port Kembla. Despite a widespread survey of suitable habitat, the four sites described in this study are all that remains of a formerly widespread population in the Illawarra (White and Pyke 1996)[1]. Much of the bell frog's preferred habitat in the Illawarra has been destroyed or modified. An extensive swamp once occurred in the vicinity of the golf course at Primbee, which contained hundreds of adult bell frogs (L. Smith, pers. comm.). This breeding habitat has since been destroyed and no bell frogs have been recorded in this area recently. A single bell frog was recorded in a quarry at another site in Port Kembla, which has since been filled in (Goldingay 1996).

The Gloucester Boulevard site has been modified by earthworks in order to develop the land for housing. This has resulted in drainage of one of the soaks which prevents the accumulation of sufficient standing water for breeding. The drainage channel present actually drains water onto the beach. Given that the mean bell frog spawn size in this population is 5 706 (van de Mortel 1996), to find six tadpoles at the site suggests recruitment has fallen to a very low level here. The population at Coomaditchy has also been disturbed. Shortly after we recorded 400 metamorphlings at the lagoon in long grass and in two tall *Typha* beds adjacent to the lagoon, council workers mowed the *Typha* and the grass.

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[1] The data reported here formed the basis of those included in Table 3 of White and Pyke (1996) for the Port Kembla and Primbee sites but were misreported. The data presented by them for Killalea Lagoon (Shellharbour) are also incorrect. These bell frogs were detected at Killalea in January 1994 (A. White, pers. comm.). This is the only record since before 1990 despite many surveys (C. Chafer, pers. comm.; van de Mortel and Goldingay unpubl. data).

An interesting finding of this study was the variation in numbers of bell frogs at the survey sites over time. This has implications for population monitoring and the detection of bell frogs at new sites (see below). In recent times, bell frog tadpoles (>20) and metamorphlings (<5) were located at Coomaditchy in January 1993 by Dr D. Skelly from the University of Wollongong. Intensive (>2 h each) daytime surveys conducted by him on two other occasions in 1993 failed to detect any adults at the site (D. Skelly, pers. comm.). Daly (1995) also recorded a small number of metamorphlings at one site on the lagoon in early 1993. A diurnal survey in February 1994 detected eight adult frogs sheltering in cumbungi (Goldingay, pers. obs.). Several follow-up visits at night in 1994 failed to detect any bell frogs in the same area. The fluctuation in bell frog numbers at Coomaditchy and Gloucester Boulevard, located about 1 km away, suggests that there may be regular movements among these sites. A similar finding has been reported by White and Pyke (1996) for the bell frogs at Kurnell in Sydney.

One of the most important findings of this study is the confirmation that bell frogs are breeding in water that contains a high density of Mosquito Fish. Exotic fish have been proposed as a principal cause of bell frog declines. Pyke and White (1996) reported a strong negative correlation between exotic fish and breeding by bell frogs. Morgan and Buttemer (1996) demonstrated that Mosquito Fish can cause high mortality in bell frog tadpoles. The evidence provided by this study for the coexistence of tadpoles and Mosquito Fish was the observation in January 1996 that bell frog tadpoles were abundant (>100) in the water of the lagoon concurrently with large numbers of Mosquito Fish. Moreover, observations of over 400 metamorphlings confirmed that breeding could be successful in the presence of fish. Subsequently, the presence of 63 adult bell frogs — more than double the maximum number of adults seen in the previous year — suggested that this breeding event had led to recruitment to the adult population.

Management implications

These findings have important implications for the conservation and management of the Green and Golden Bell Frog throughout New South Wales. Firstly, coexistence and successful breeding in the presence of the Mosquito Fish at Coomaditchy Lagoon suggest that this site may have some quality that is different to other fish-infested sites from which bell frogs have disappeared. Morgan and Buttemer (1996) reported much greater survival of tadpoles when pond weed was added to treatments containing fish compared to controls. This suggests that the presence of appropriate submergent vegetation may be a critical habitat component for bell frog breeding. Observations of bell frog tadpoles at Coomaditchy showed that they did in fact inhabit the benthic area where there was a dense detritus and vegetated layer (R. Goldingay, pers. obs.). Modification of aquatic vegetation may provide a much simpler and long-lasting method for managing bell frog sites colonized with Mosquito Fish, when compared to other methods such as draining ponds, providing ephemeral ponds or poisoning the water.

A second finding is the relative ease with which surveys for bell frogs can be conducted. Despite the fact that bell frogs may not always be detected at sites they occupy, we were able to detect frogs active at night during winter, and we observed adult and juvenile frogs during both diurnal and nocturnal surveys in the summer. The number of bell frogs was correlated significantly with both temperature and rainfall at Gloucester Boulevard but not at Coomaditchy Lagoon. One major difference between the two sites is that Coomaditchy Lagoon is a permanent water body whereas there is little or no standing water at Gloucester Boulevard in dry weather. These site differences should be kept in mind when planning bell frog surveys. Conducting surveys on several nights after rain during summer may be the most appropriate method for obtaining indices of population levels for long-term monitoring.

Given that bell frogs were only found at Korungulla on three out of 10 visits, surveys may need to be conducted over an extended period before concluding that frogs are not present. Surveys in late December through to February can be conducted for juvenile frogs. Our experience is that these frogs tend to be more frequently observed in grassy areas adjacent to breeding sites. It should be recognised that our counts are unlikely to be absolute counts of the total population and that more adults are likely to occur in the area. The population size will only be determined more precisely by permanently marking frogs in the population. The use of PIT tags is likely to be the most appropriate technique (Christy 1996).

A consideration for the Port Kembla population is that there are different types of habitat occupied by the frogs which will require different forms of management. The frogs occupy a lagoon site surrounded by houses and parkland, they occupy a drainage channel and associated ephemeral ponds surrounded by housing and a factory, and they occupy an inundated area within the steelworks. Each of these sites will require specific management strategies. The first management issue we considered for this population was the way the grassland was being mowed at the lagoon site. Our recommendations have led Wollongong City Council to exclude mowing from a 10 m wide strip of grass around the perimeter of the lagoon and from two small areas of cumbungi growing in seepages away from the lagoon. The grass and the cumbungi were the main resting, and possibly foraging, sites of juvenile bell frogs. Further studies are required to determine which other areas near the lagoon may be important at different times for the frogs.

An interesting phenomenon with the Port Kembla bell frogs is that their breeding habitats are located very close to houses and roads. Gardens in yards provide shelter sites that are frequently used by frogs in this population. It is therefore appropriate to develop an understanding within the local community about the importance of these frogs and to develop strategies that may lead to an improvement in the quality of the habitat present in many gardens. Furthermore, the mobility of the population suggests that road crossings and house pets may become important sources of mortality and may require some form of management.

Lastly, it has been recognised that bell frogs need to be conserved at a regional scale, to prevent loss of genetic diversity and to enhance overall conservation prospects (Goldingay 1996). Given the size of the local population and the distance from other bell frog populations, we recommend that the Illawarra should be the regional unit used for the conservation of the bell frogs in this area. This separates it from the Shoalhaven region as a regional unit (see Goldingay 1996). This will require providing at least three isolated sites in the Illawarra where bell frogs can be conserved. Further studies are needed to determine the most appropriate sites.

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